Energy and Environmental Effects of Green Roofs

why context matters…

NASA – 2012 International Workshop on Environment and Alternative Energy

Greenbelt MD
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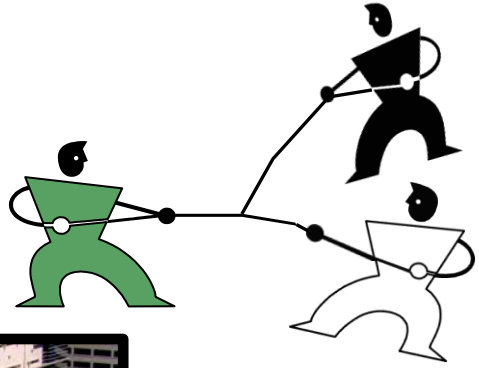
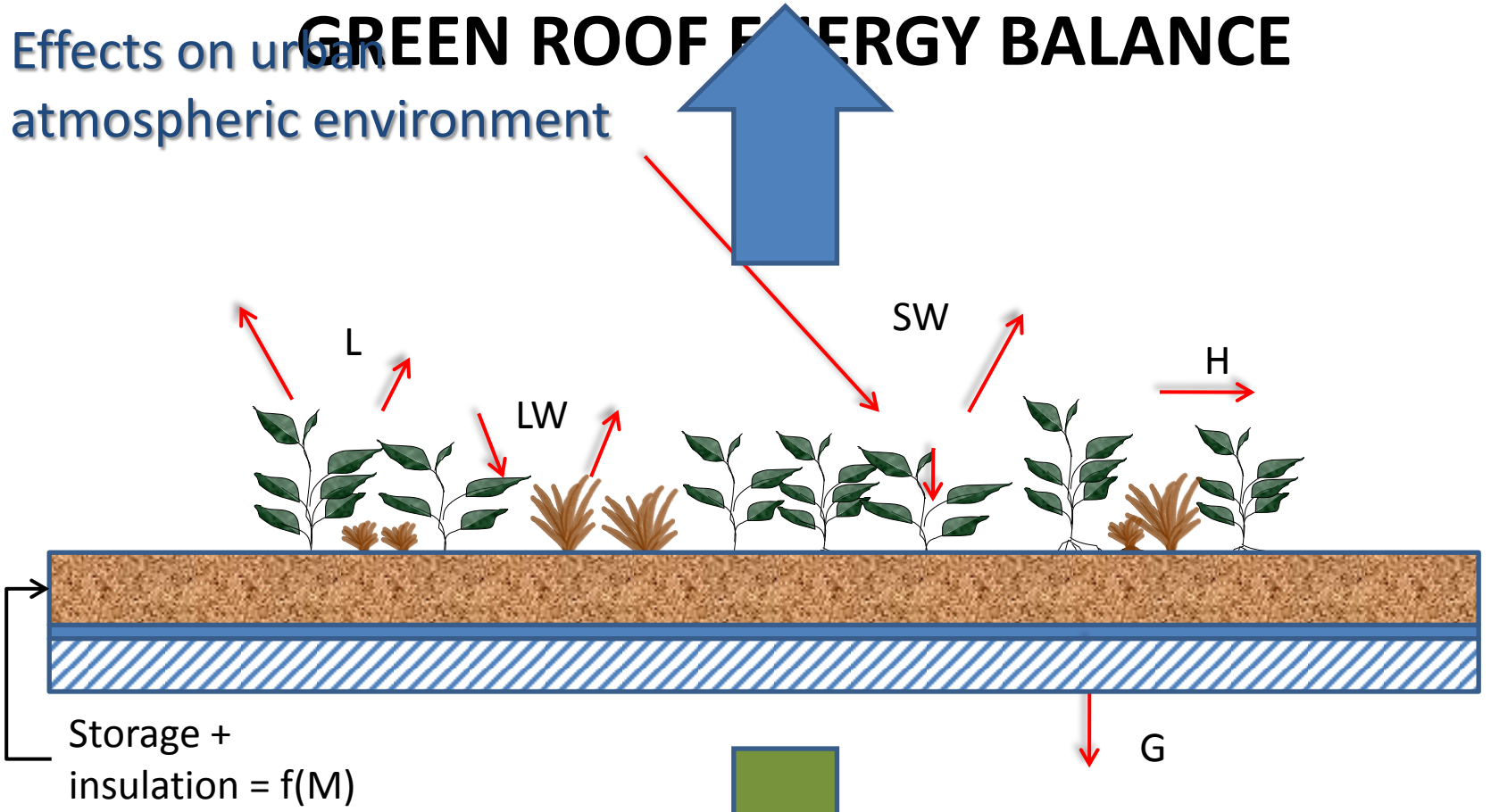
Sustainable Roofing and the Building Sector



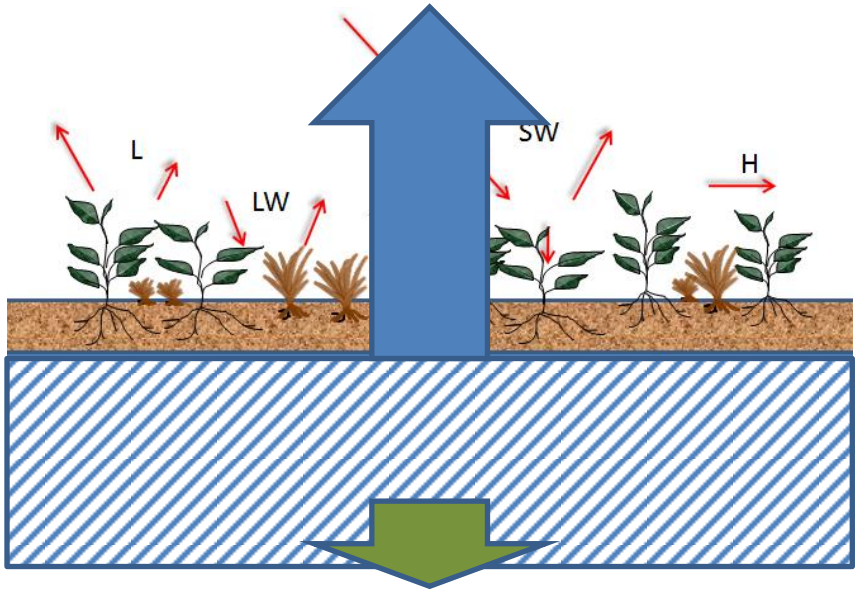
GREEN ROOF ENERGY BALANCE

Effects on urban atmospheric environment



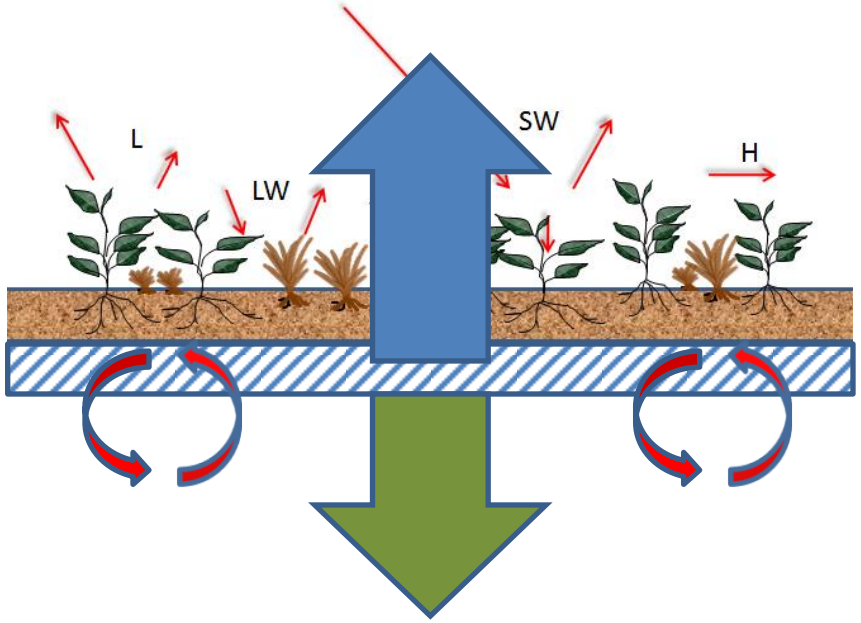
Effects on building energy use

… but application matters



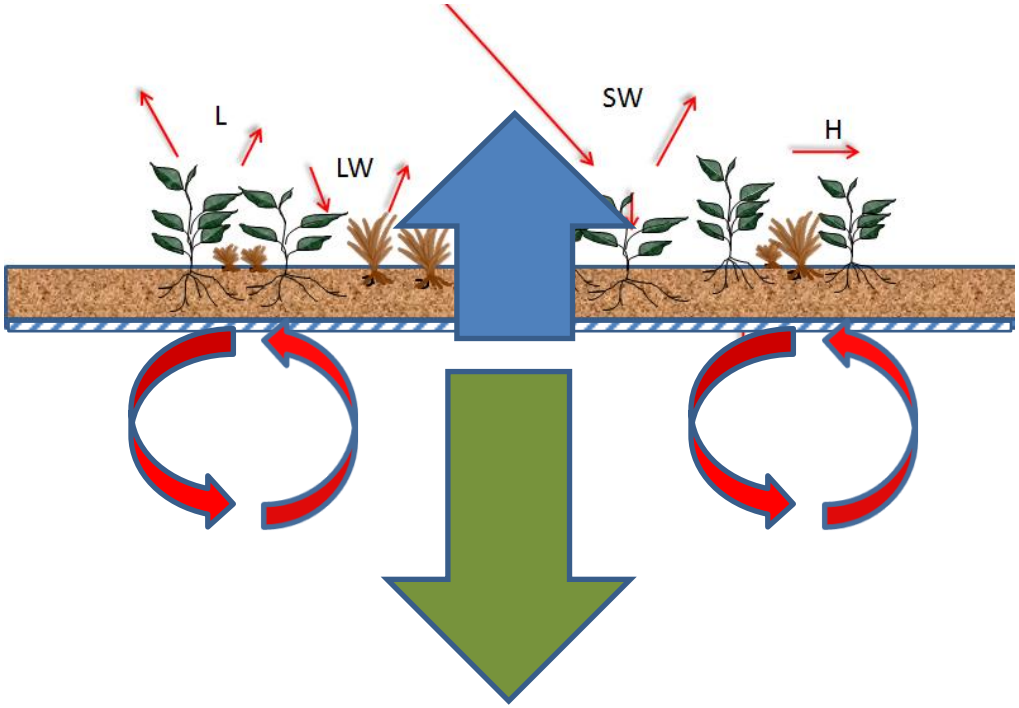
Applied above a well-insulated roof

- Green roof energy balance is largely decoupled from the building, having more of an impact on the urban environment



Applied above a less-insulated roof

- Green roof energy balance significantly affects both the building and the urban environment

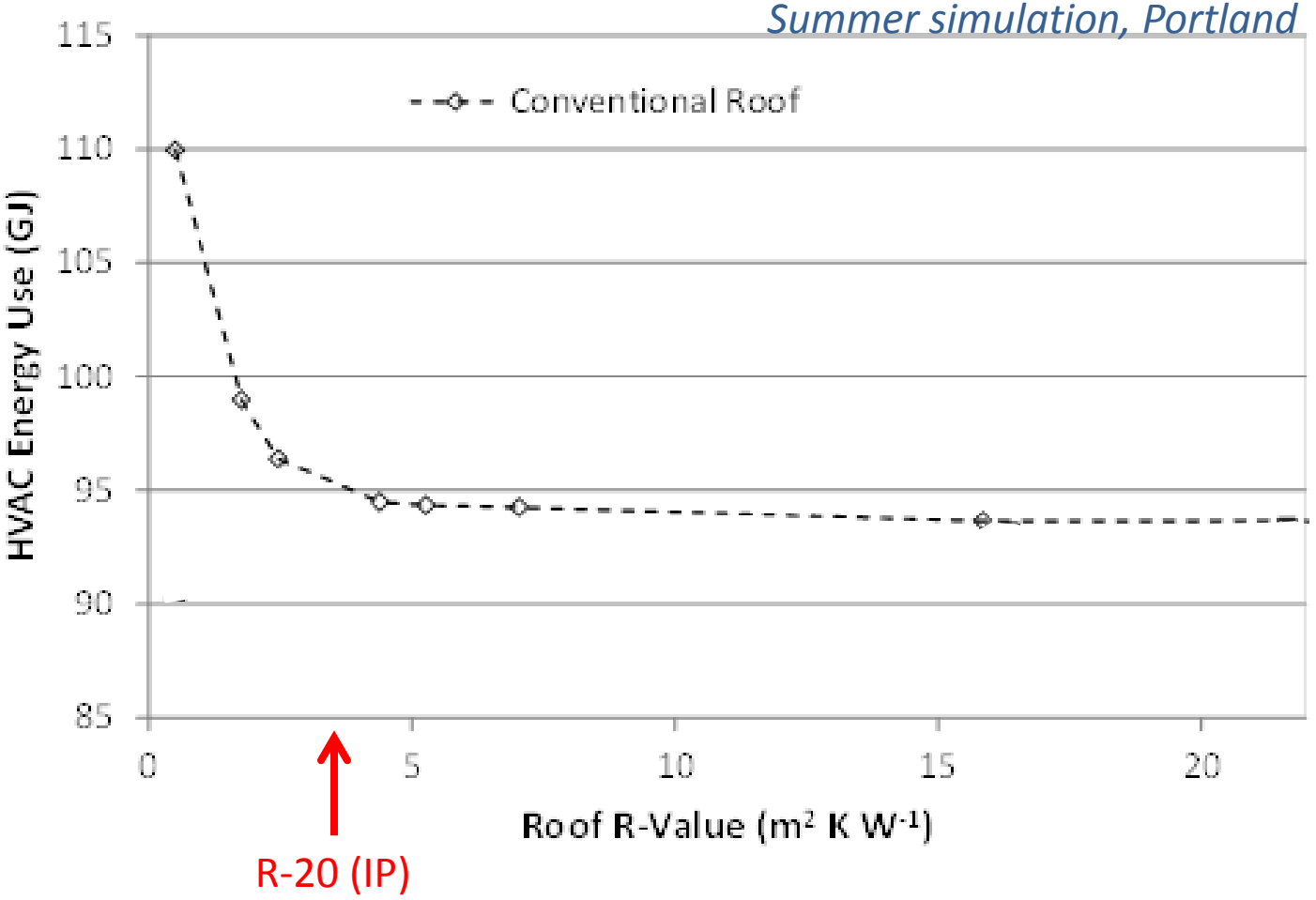


Applied above an un-insulated roof

- The commonly referenced result from studies such as Niachou et al., 2001, ORNL 2010, etc.
- “up to 50% HVAC energy savings” and similar statements

…adding insulation to a green roof can decouple the roof and reduce the effectiveness of evaporative cooling

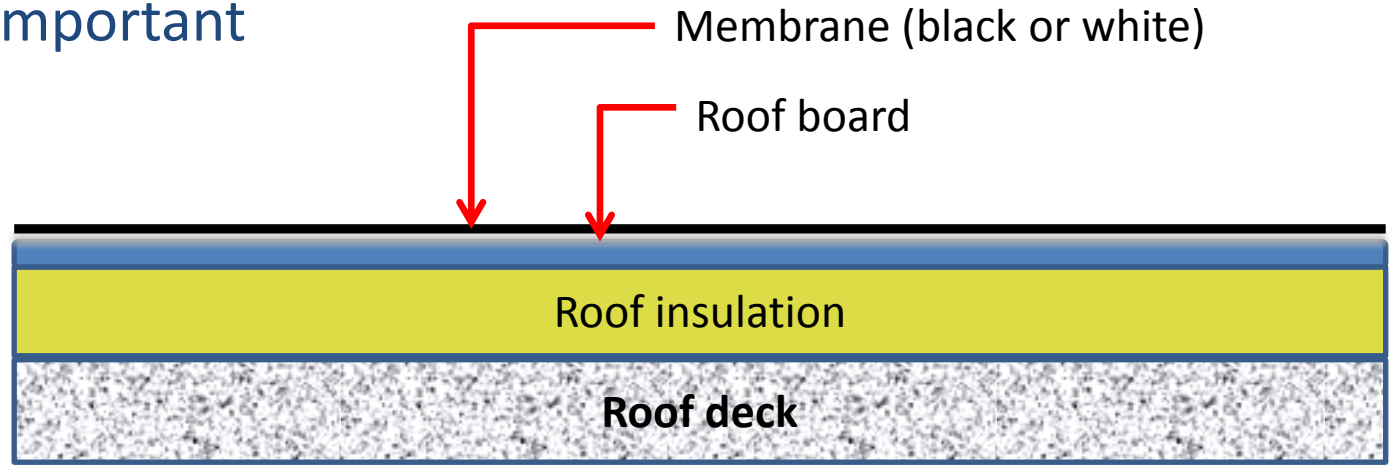
Summer simulation, Portland



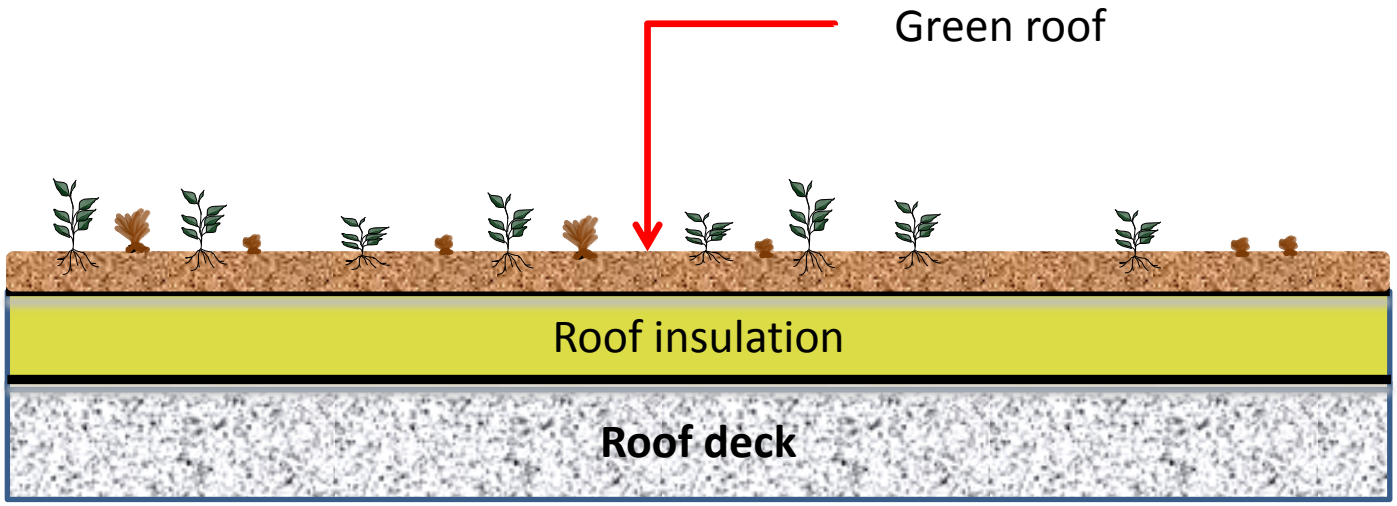
Moody and Sailor, 2012

…thermal mass is important

Little thermal mass above insulation…

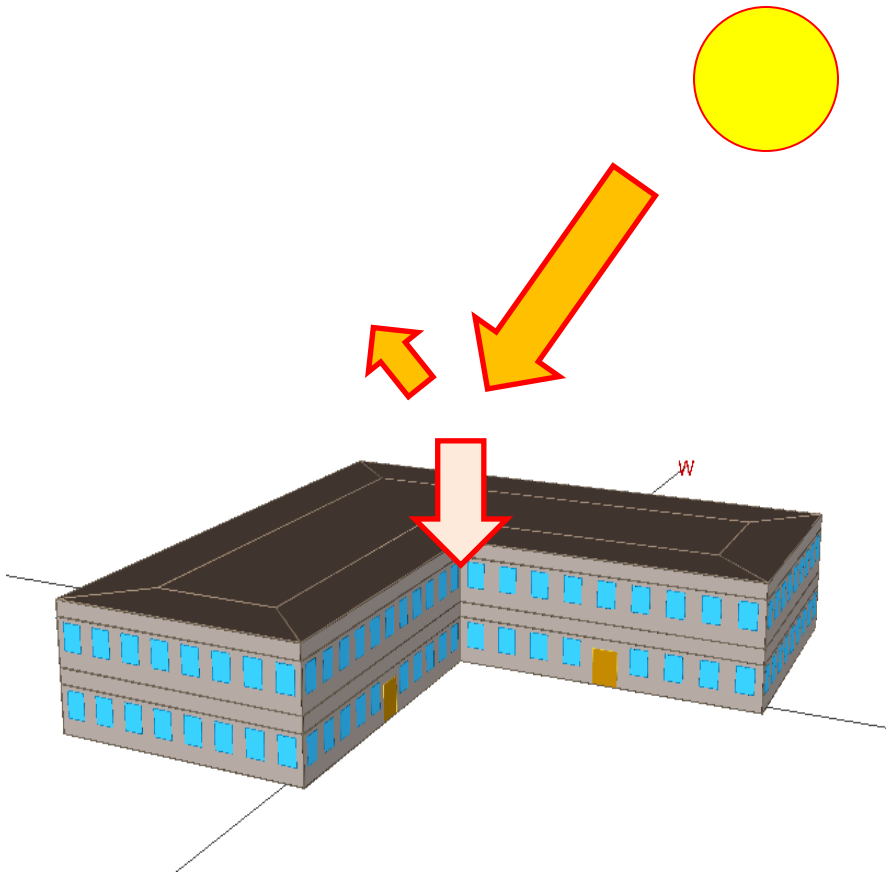


Some thermal mass above insulation…



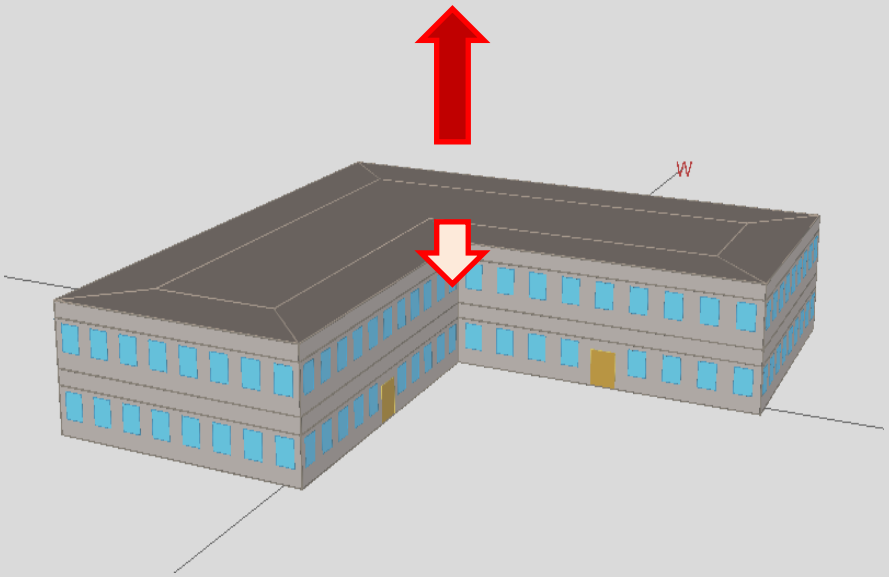
Conventional Roof – Day

(dark membrane)



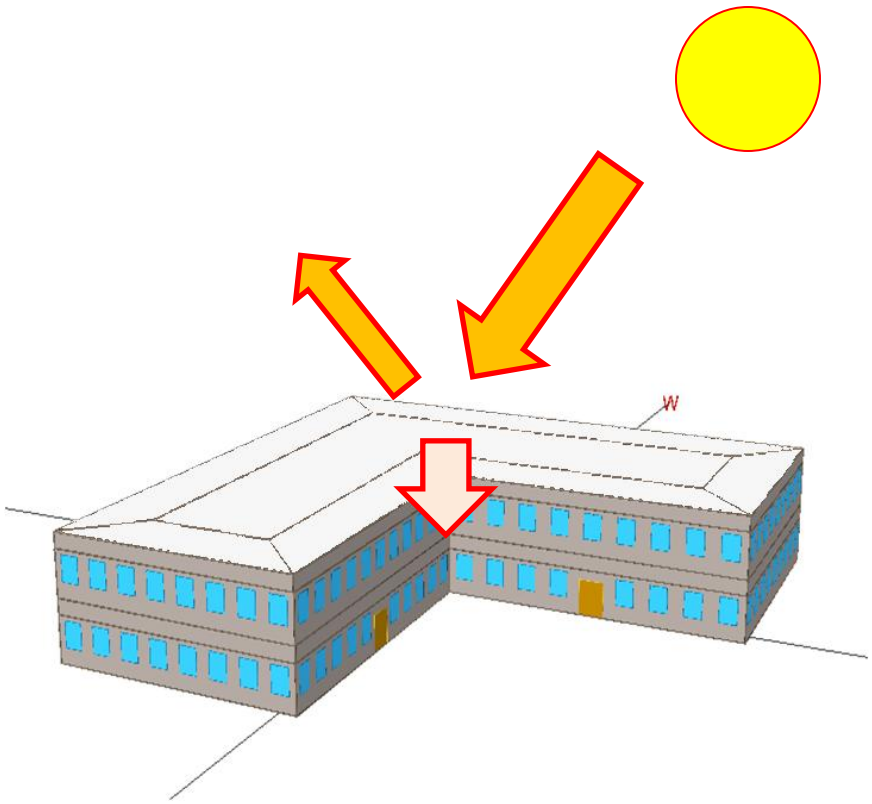
Heats up rapidly during summer day…

Conventional Roof -- Night



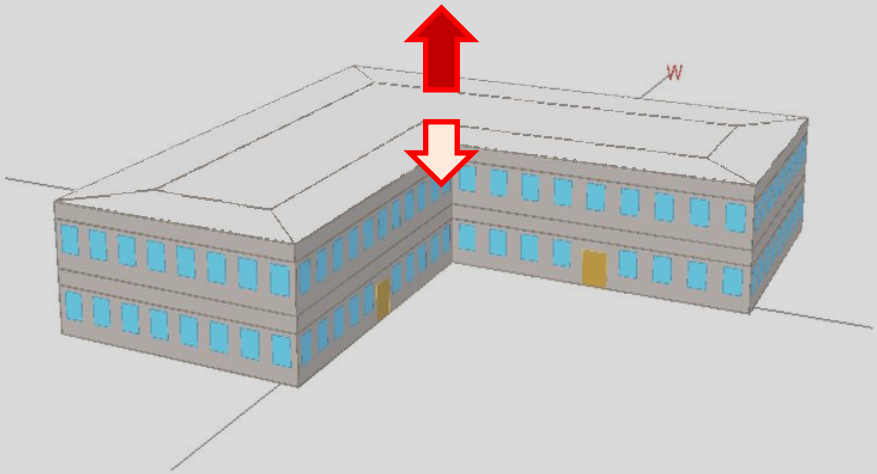
…but cools off rapidly at night.

“Cool” White Roof -- Day



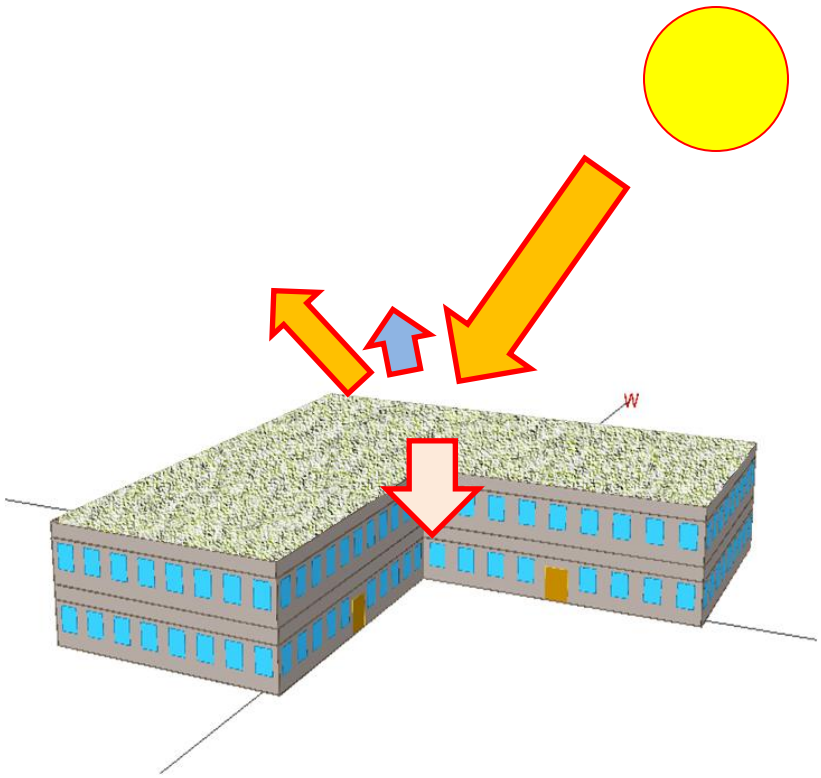
Doesn’t heat up as much during summer day…

“Cool” White Roof -- Night



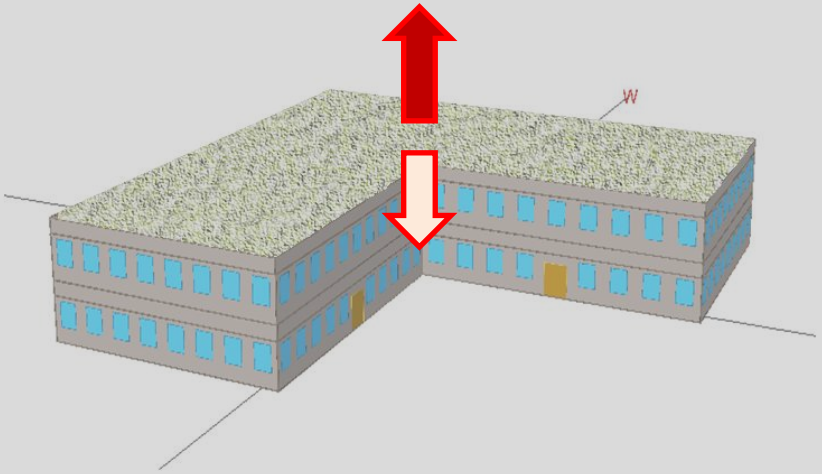
…and cools off significantly at night.

Green Roof-- Day



Doesn't heat up much during summer day…

Green Roof- Night

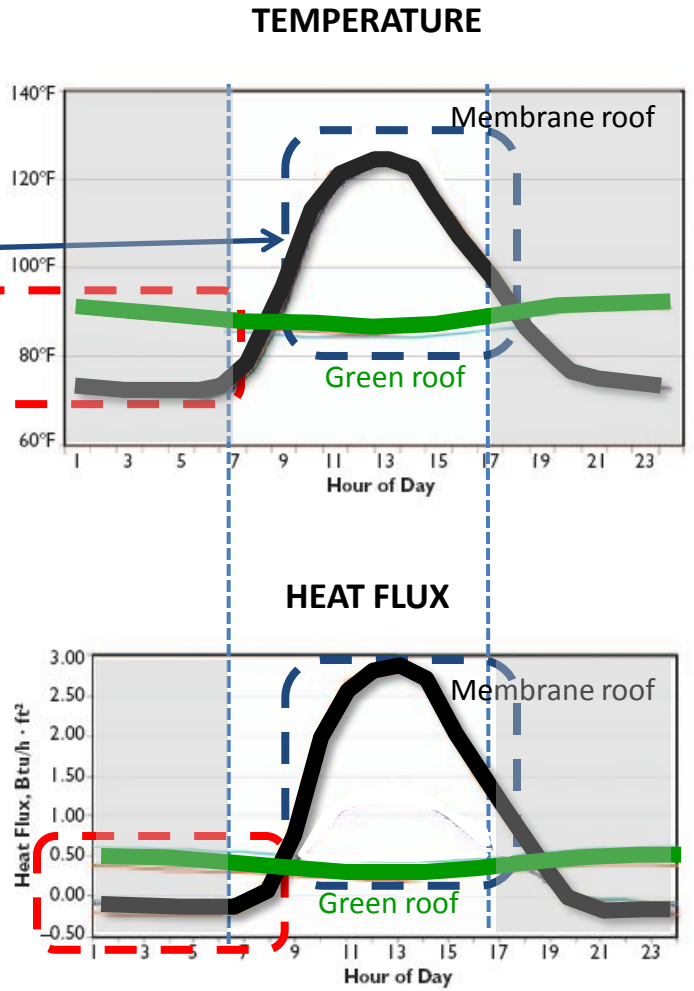


…but remains warm at night due to stored heat.

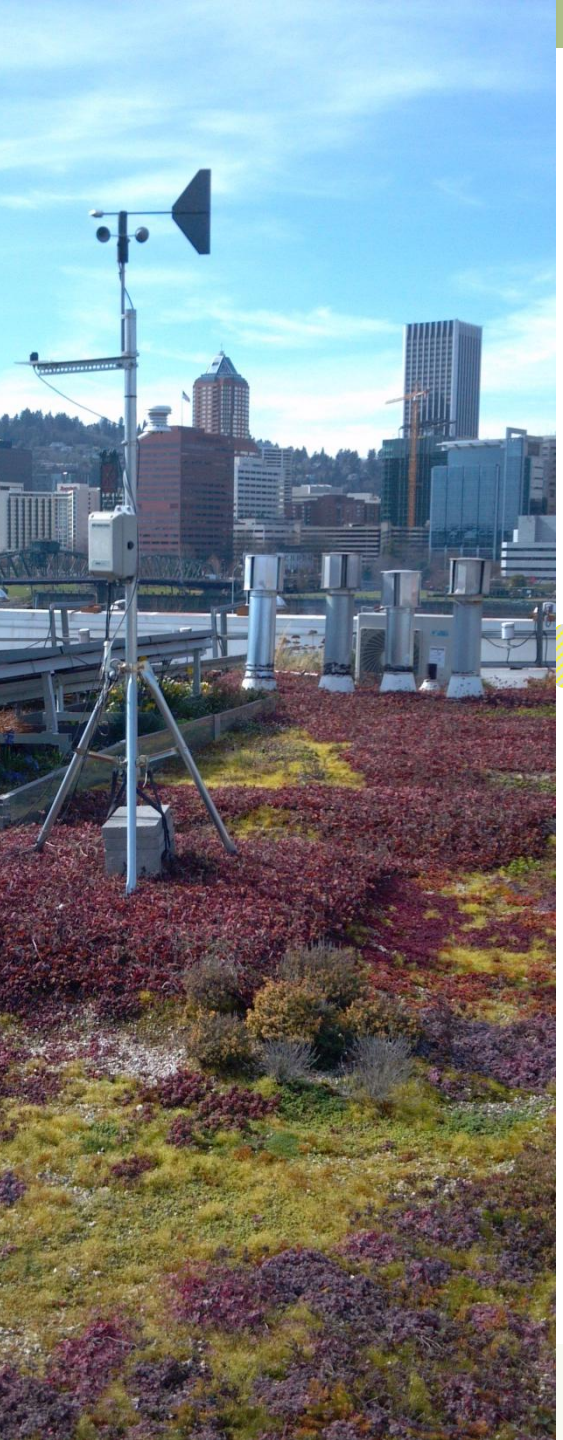
Green Roof vs. Membrane Roofs in Florida

Green roof is ~30-40 ° F cooler during a summer day.

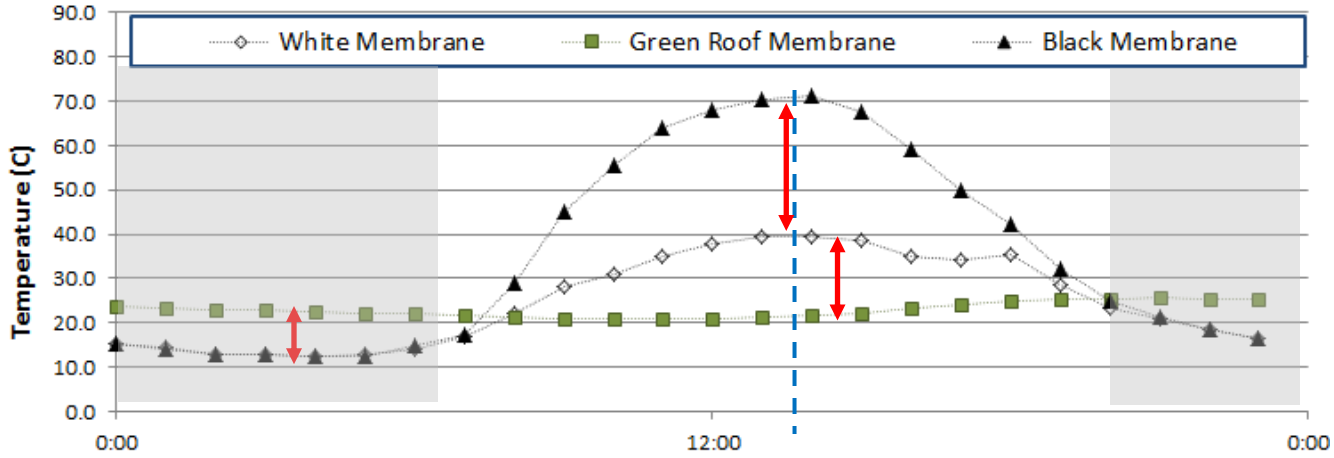
Green roof is warmer by ~20 °F at night



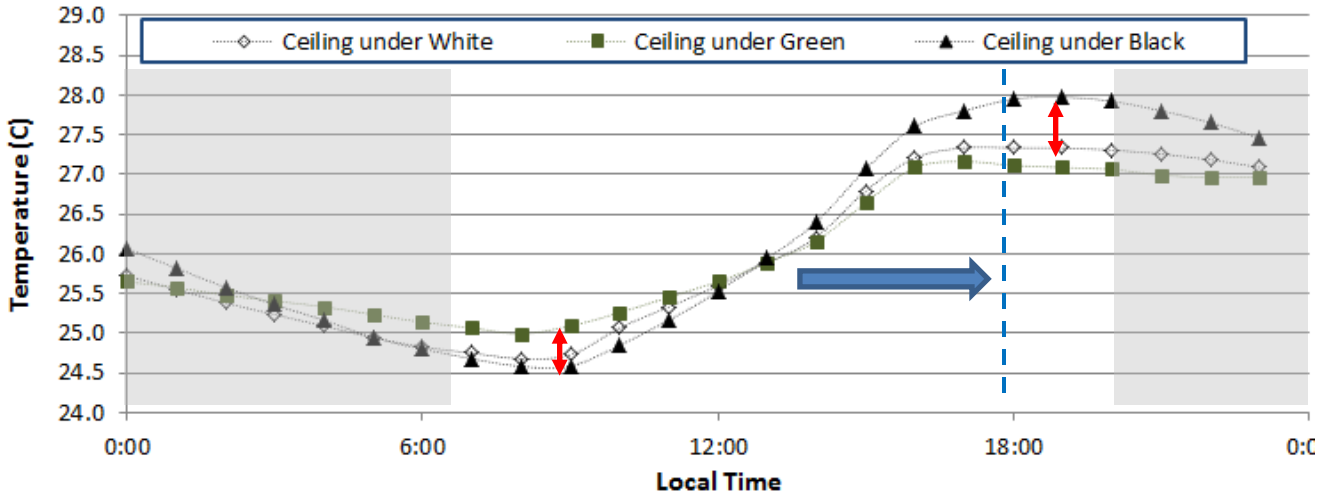
Student Union,
University of Central Florida
Courtesy J. Sonne, FSEC



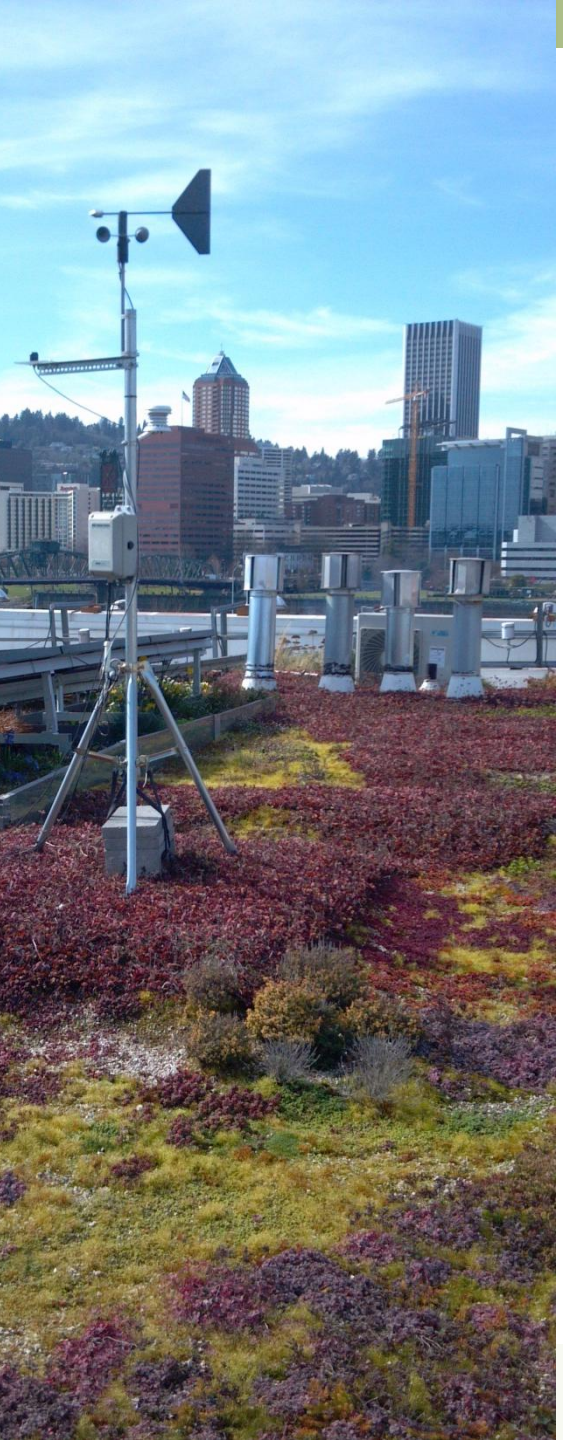
Green Roof vs. Membrane Roofs in Oregon



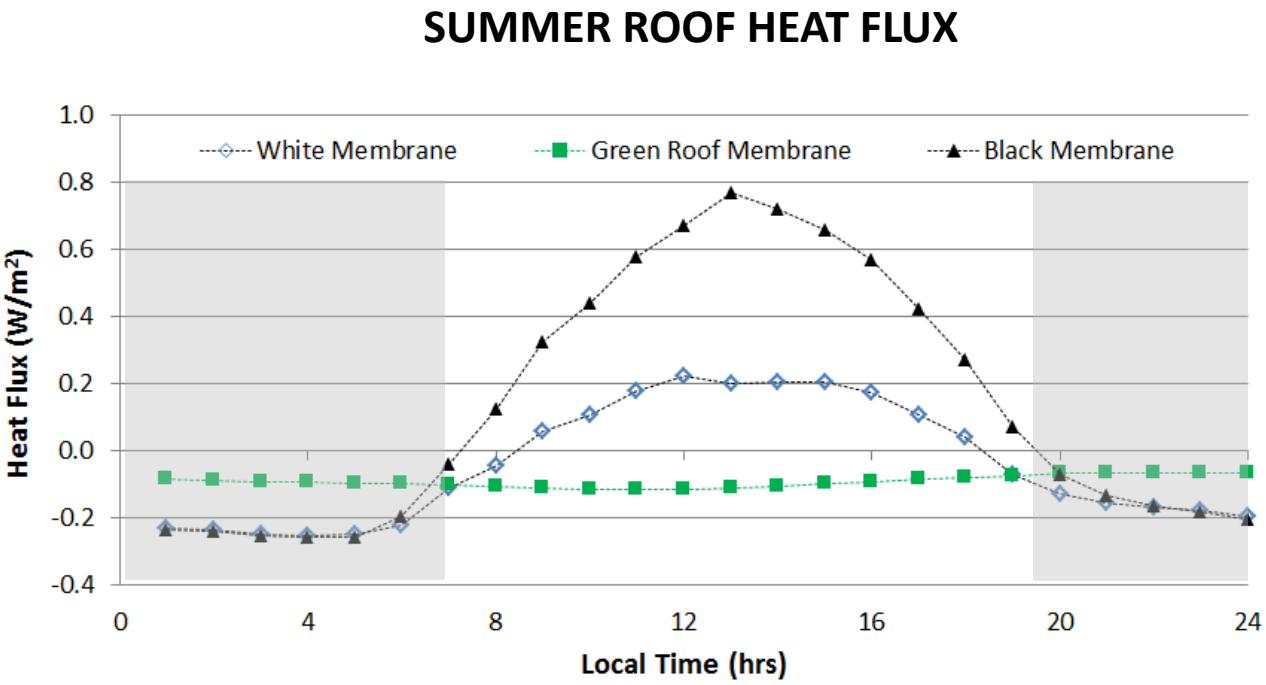
Roof Insulation (R-30)



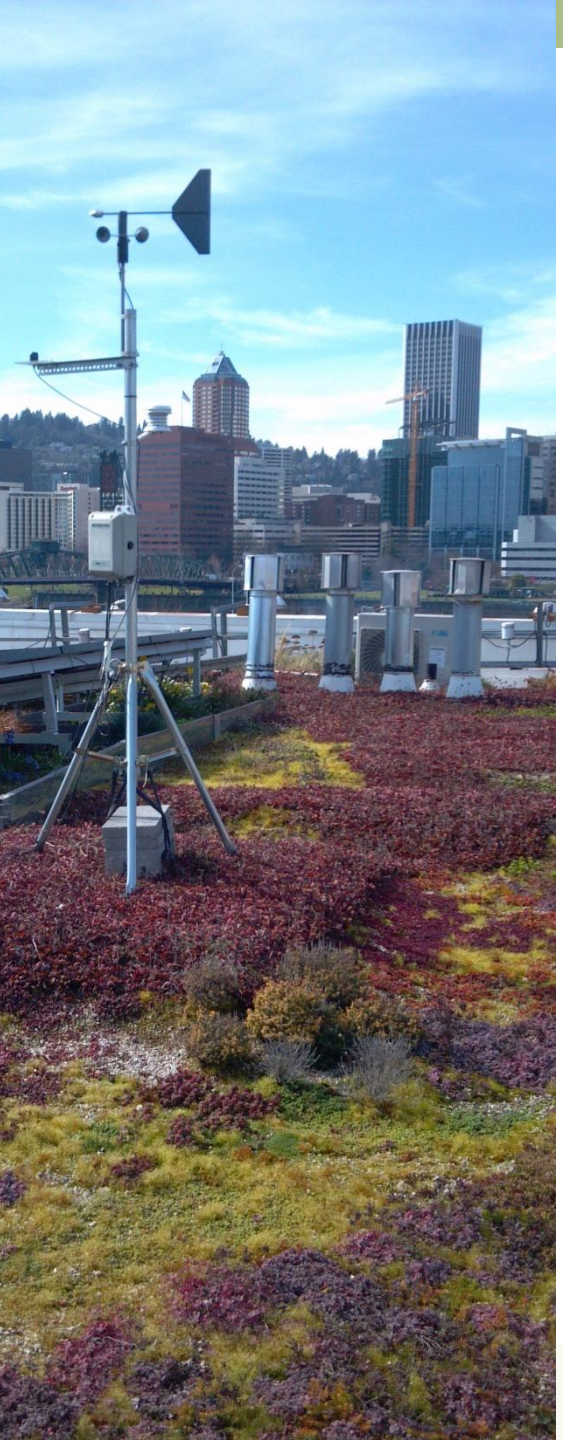
International Harvester Building, Portland, Oregon
July 10-11, 2012



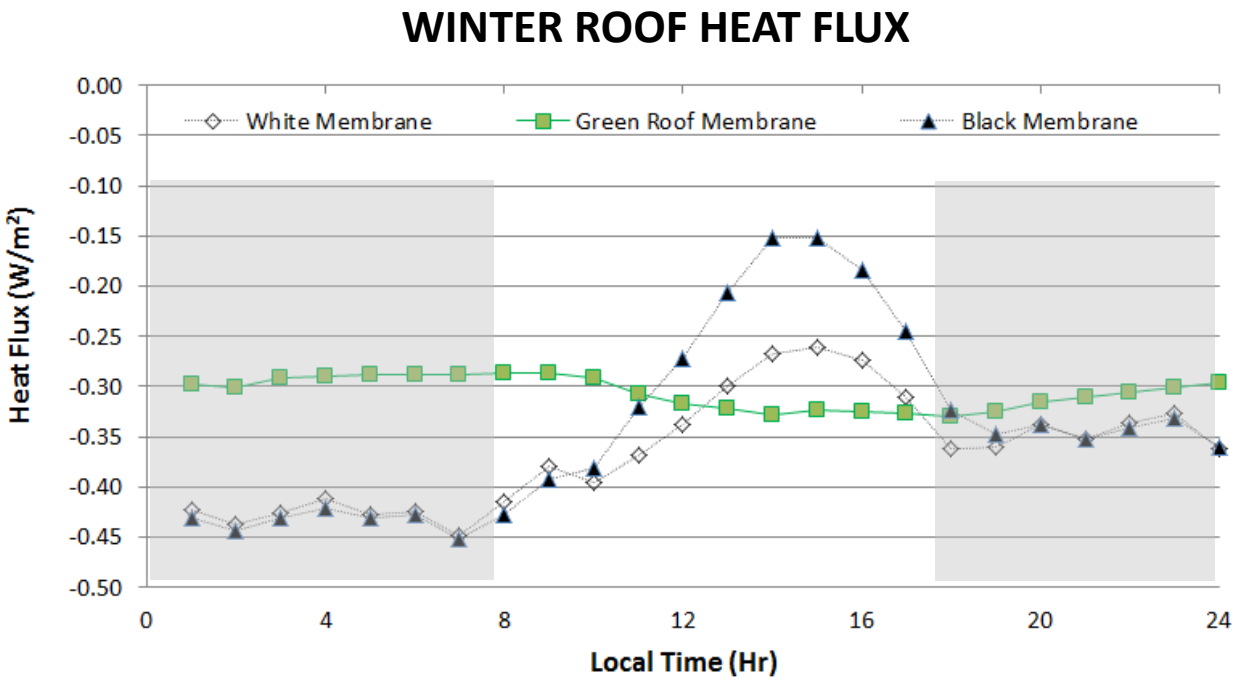
Green Roof vs. Membrane Roof in Oregon



International Harvester Building, Portland, Oregon
July 3, 2012



Green Roof vs. Membrane Roof in Oregon

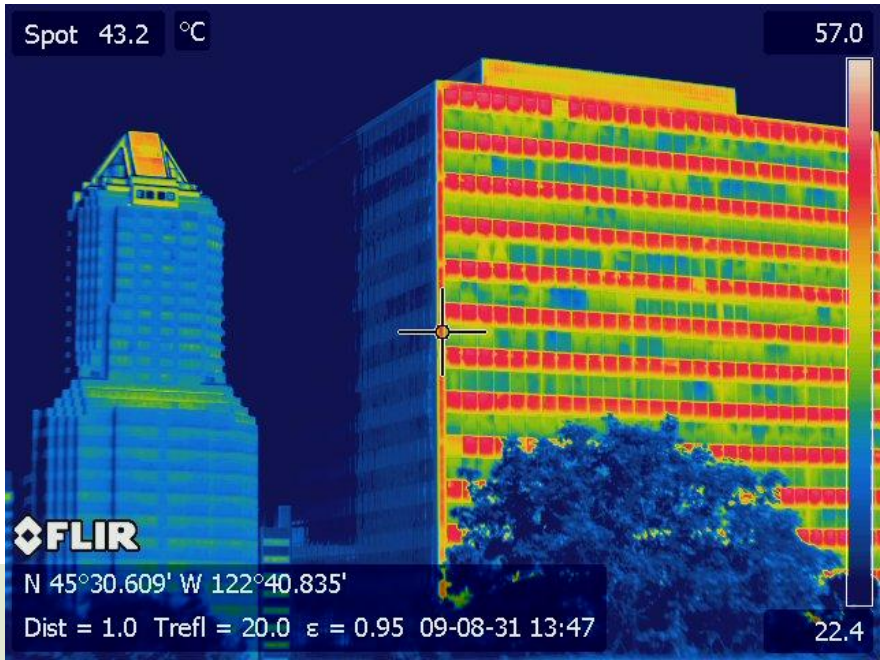


International Harvester Building, Portland, Oregon
Jan 4, 2011

…but roof heat flux is just one factor affecting HVAC loads

Contributors to building HVAC energy use

- Solar heat gain through windows
- Indoor energy use for lighting & plug loads
- Ventilation and infiltration of outdoor air
- Conduction through walls
- Conduction through roof
- Interactions among the above factors and HVAC controls/thermostats.



…building type and load/occupancy schedules also matter

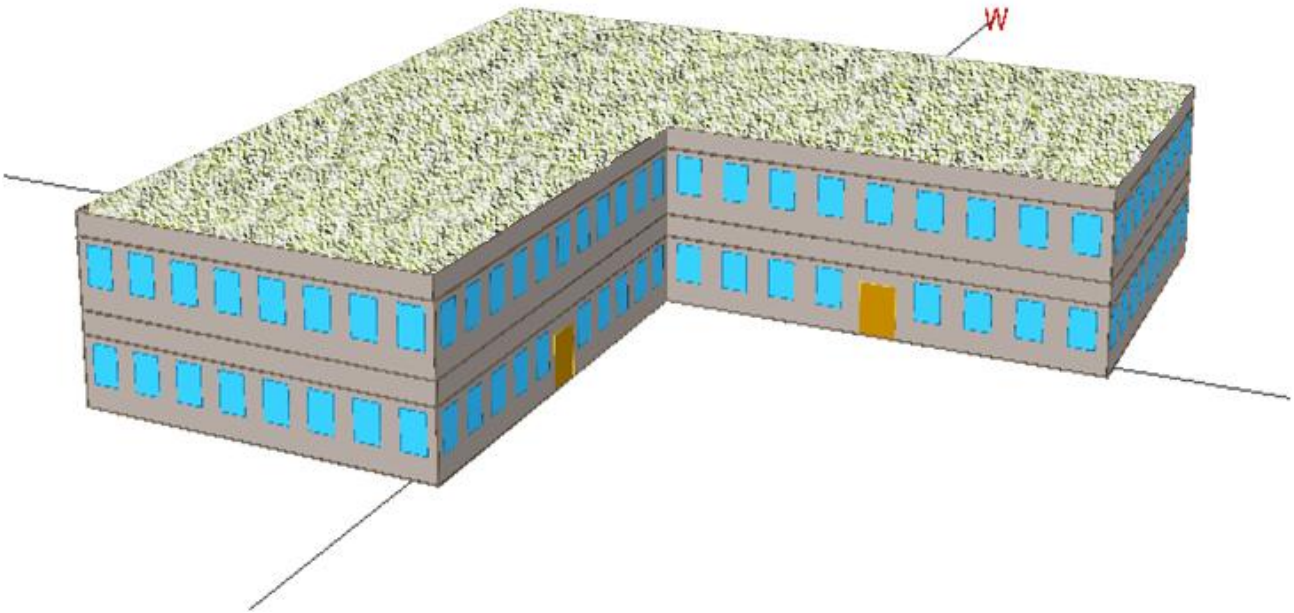
Office buildings:

- Internal gains and air exchanges are large
- Occupancy mainly during day

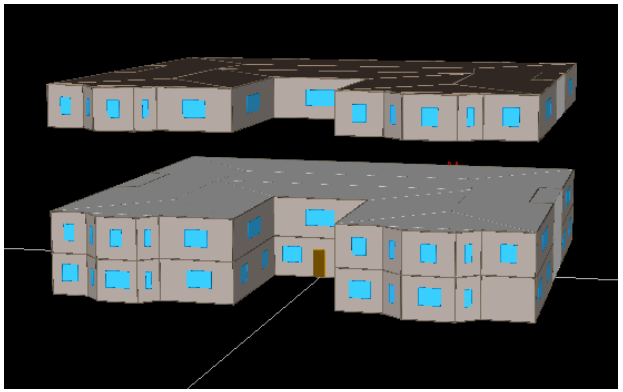
Apartment buildings:

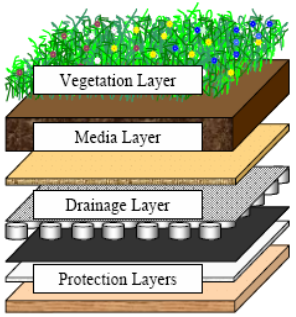
- Internal gains more modest
- Occupancy rates higher at night

…ultimately, we are interested in whole building annual energy use for both heating and cooling



Solution: whole-building energy simulation software



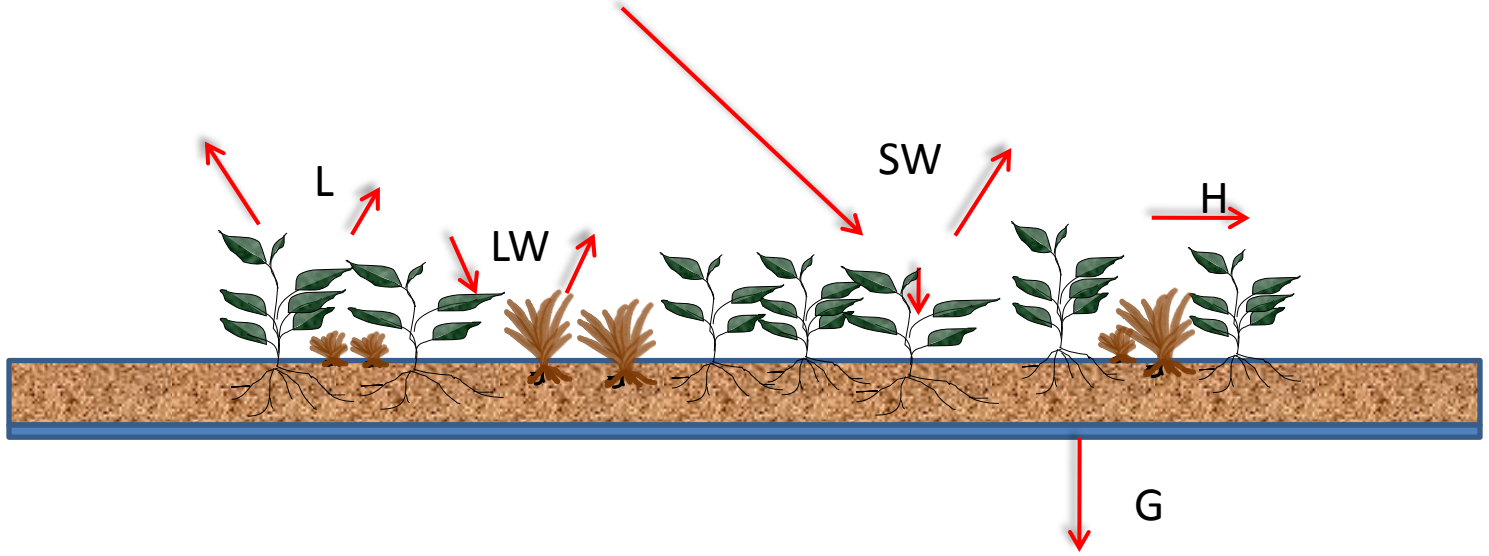


FOLIAGE

$$F_f = \sigma_f \left[I_S^{\downarrow}(1-\alpha_f) + \varepsilon_f I_{ir}^{\downarrow} - \varepsilon_f \sigma T_f^{\,4} \right] + \frac{\sigma_f \varepsilon_g \varepsilon_f \sigma}{\varepsilon_f + \varepsilon_g - \varepsilon_f \varepsilon_g} \left(T_g^{\,4} - T_f^{\,4} \right) + H_f + L_f$$

GROUND SURFACE

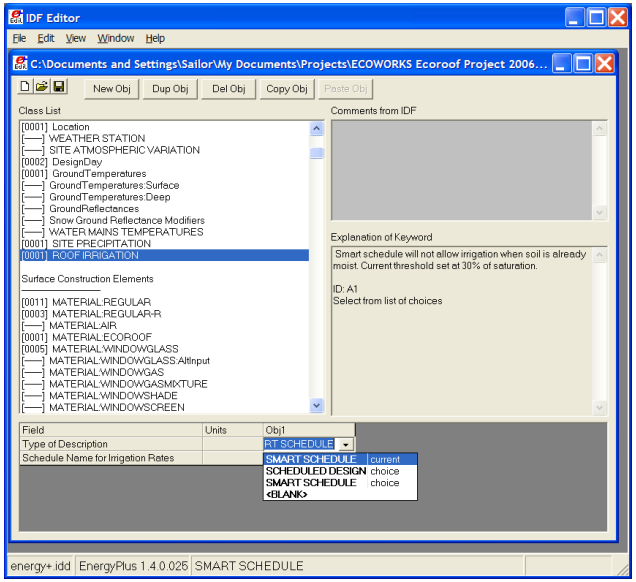
$$F_g = (1-\sigma_f)\left[I_s^{\downarrow}(1-\alpha_g) + \varepsilon_g I_{ir}^{\downarrow} - \varepsilon_g T_g^4 \right] - \frac{\sigma_f \varepsilon_g \varepsilon_f \sigma}{\varepsilon_f + \varepsilon_g - \varepsilon_f \varepsilon_g} \left(T_g^4 - T_f^4 \right) + H_g + L_g + K * \frac{\partial T_g}{\partial z}$$



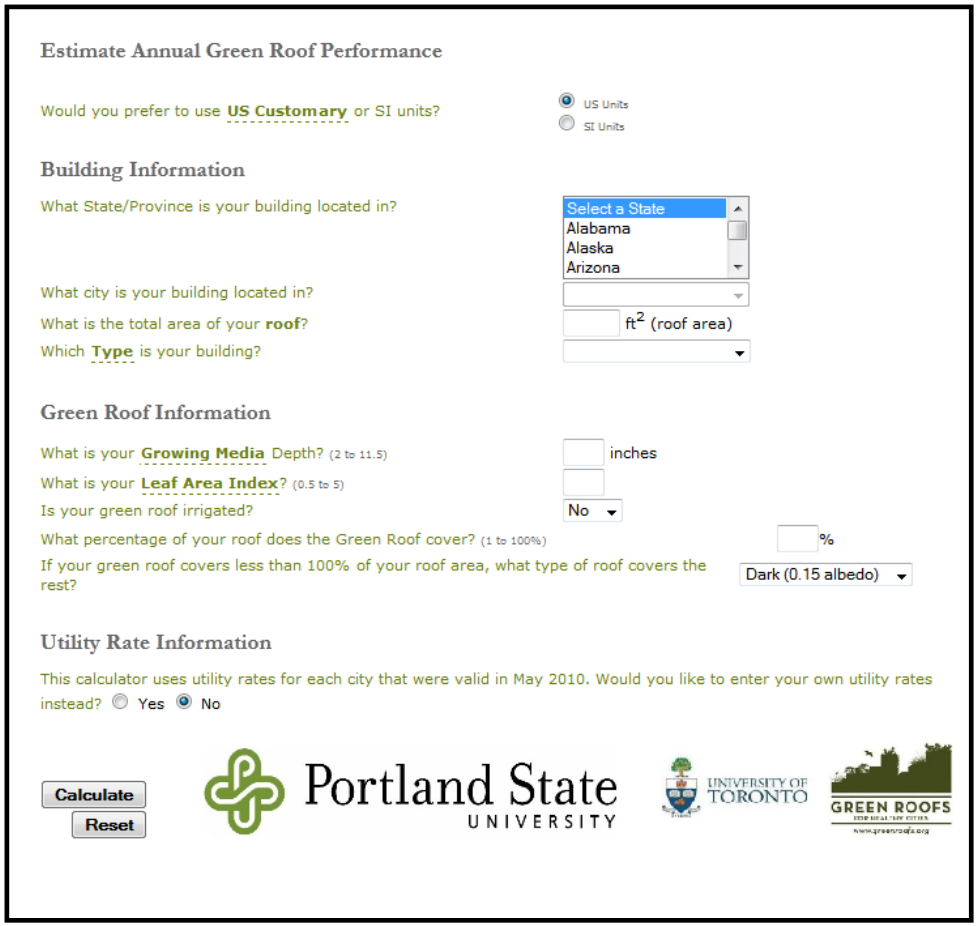
Sailor, D.J., 2008, *Energy and Buildings* **40** (8), 1466-1478.

Green Roof Energy Models

- **Full physics of green roof energy balance**
- **Standard in EnergyPlus**
  - Starting with v 2.1 in April 2007



- **Green Roof Energy Calculator**
  - http://greenbuilding.pdx.edu/grcalc.html
  - Database driven using 8000 simulations
  - Version 2.0 (2011)



Sailor, D.J., 2008, *Energy and Buildings* **40** (8), 1466-1478.

http://greenbuilding.pdx.edu/GR_CALC_v2/grcalc.html

Would you prefer to use **US Customary** or SI units?

- (•) US Units
- ( ) SI Units

Building Information

What State/Province is your building located in?

Oklahoma
Oregon
Pennsylvania
Rhode Island

What city is your building located in? Portland

What is the total area of your **roof**? 25000 ft^2 (roof area)

Which **Type** is your building? Old Office Bldg.

Green Roof Information

What is your **Growing Media** Depth? (2 to 11.5) 4 inches

What is your **Leaf Area Index**? (0.5 to 5) 3

Is your green roof irrigated? Yes

What percentage of your roof does the Green Roof cover? (1 to 100%) 90 %

If your green roof covers less than 100% of your roof area, what type of roof covers the rest? White (0.65 albedo)

Calculate

Reset

You specified **an Old Office Building** in **Portland, OR** with a total roof area of 25000 ft^2. The Green Roof you specified for this building has a **Growing Media Depth** of 4 inches, a **Leaf Area Index** of 3, covers approximately 90% of the total roof area (the rest being a white roof), and is **irrigated.** For reference, the annual whole building electricity consumption for the specified green roof was 1173342 kWh and the annual gas consumption of this green roof was 3879 Therms

Annual Energy Savings compared to a Dark Roof (albedo = 0.15)

Electrical Savings:	12136.9 kWh
Gas Savings:	-0.2 Therms
Total Energy Cost Savings(1):	$751.50

Annual Energy Savings compared to a White Roof (albedo = 0.65)

Electrical Savings:	-1021.6 kWh
Gas Savings:	257.8 Therms
Total Energy Cost Savings(1):	$231.48

Average Sensible Heat Flux to the Urban Environment (W/m^2)

	Dark Roof	White Roof	90% Green Roof System
Annual Average:	32.1	-8.5	17.1
Summer Average:	69.4	10.6	30.6
Summer Daily Peak Avg.:	238.3	52.9	78.7

Annual Average:	32.1	-8.5	17.1
Summer Average:	69.4	10.6	30.6
Summer Daily Peak Avg.:	238.3	52.9	78.7

Average Latent Heat Flux to the Urban Environment (W/m^2)

	Conventional Roof	90% Green Roof System
Annual Average:	-	46.0
Summer Average:	-	58.4
Summer Daily Peak Avg.:	-	182.4

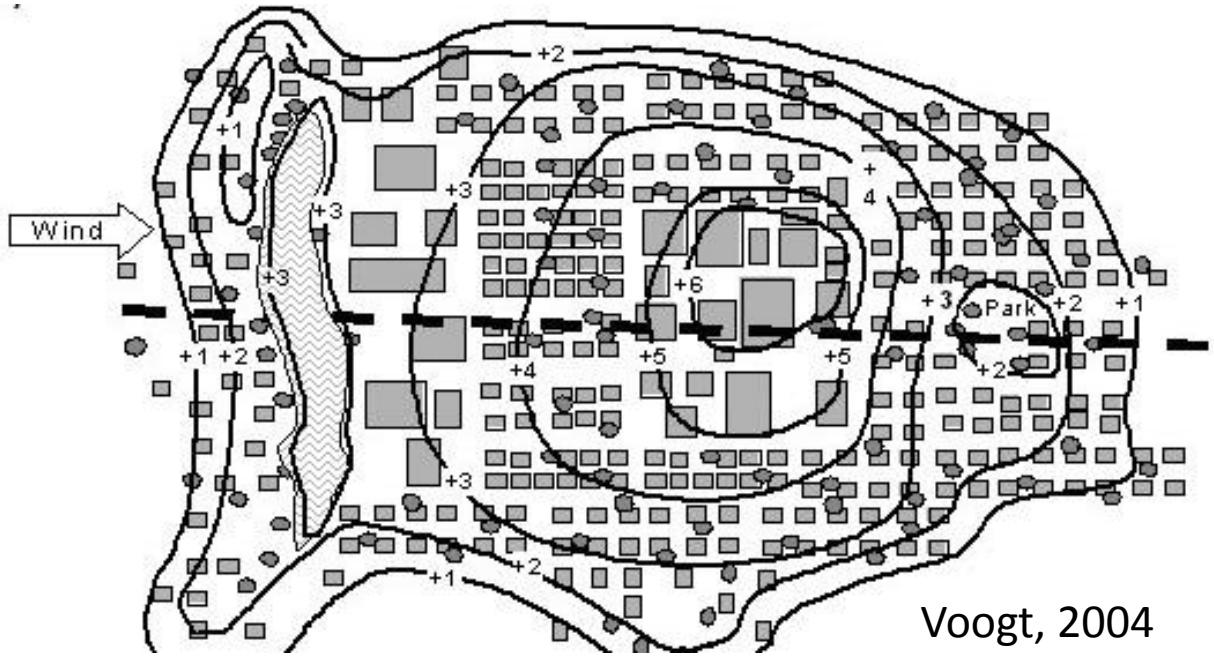
Annual Roof Water Balance (in)

	Conventional Roof	90% Green Roof System
Precipitation:	32.7	32.7
Evapotranspiration:	–	24.8
Irrigation:	–	15.1
Net Runoff (2):	32.7	23.4

NOTES: 1. due to time of day pricing the apparent financial savings/costs may not APPEAR to reconcile with the total energy savings/costs; 2. Over the course of a simulation year the net water inflow may not balance outflow due to changes in soil moisture. Also, water balance dynamics are sensitive to growing media composition, compaction, etc. As these variations are not captured in the present tool, the runoff results should be considered as order-of-magnitude estimates.

Start Over

URBAN HEAT ISLAND (UH):

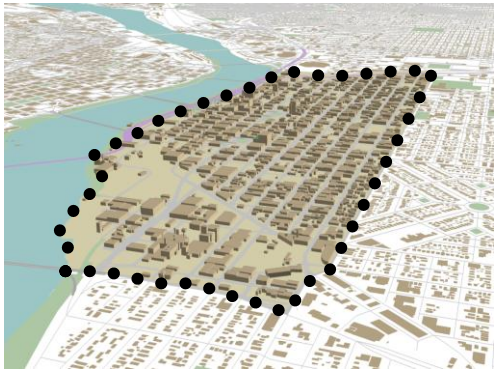


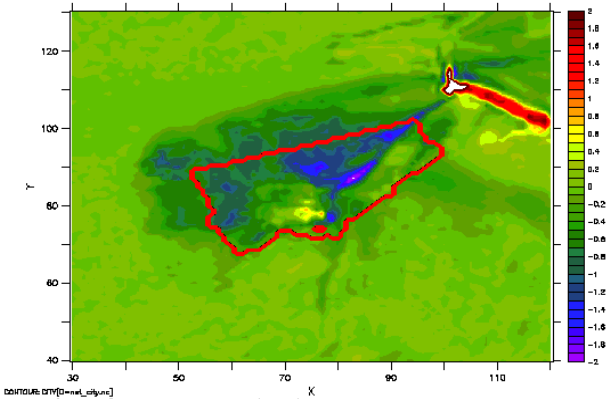
Voogt, 2004

…green roofs may be able to help cool cities

Green Roof – UHI Studies

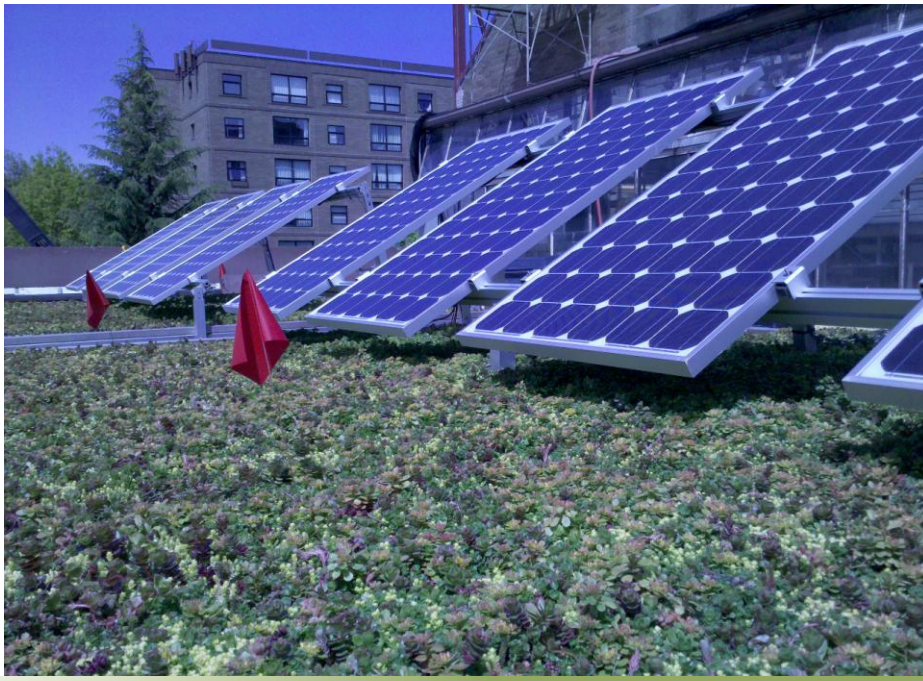
- Portland, OR
  - *100% green roofing in Central Eastside Industrial District…might reduce summer peak near-surface air temperatures by ~0.8°C (1.4°F)—if irrigated.*
- New York City
  - Green roofs *could reduce average surface temperatures …by as much as* ***0.8 ° C*** *(1.4° F) if 50% of the city's flat roofs are greened.*
- Toronto
  - Combination of green roofs and urban vegetation can reduce air temperatures by 1 to 2 °C (1.8-3.6 °F).





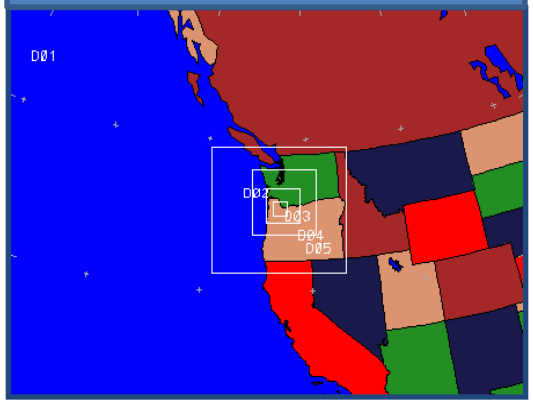
Monitoring and modeling the surface energy balance of green, white, and PV roofs

- Detailed surface energy balance model to estimate heat fluxes
- Validated with field observations
- Coupled with mesoscale atmospheric model

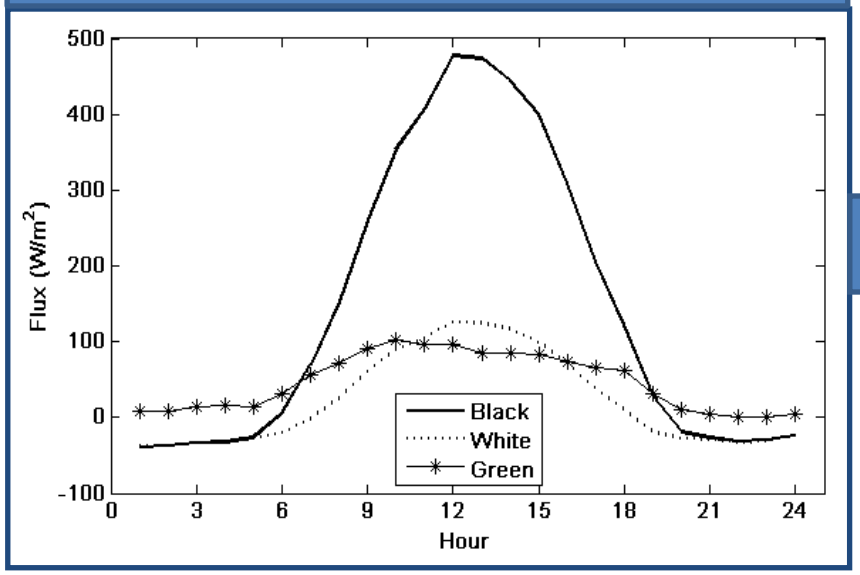


ESTIMATING UHI EFFECTS OF ROOF OPTIONS

Run mesoscale model control case (black roofs)

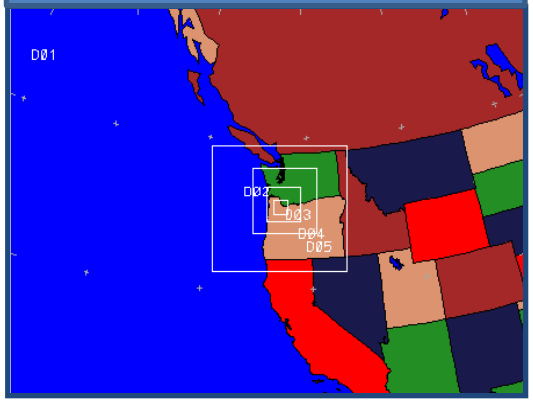


Surface energy balance model generates estimates of hourly surface fluxes

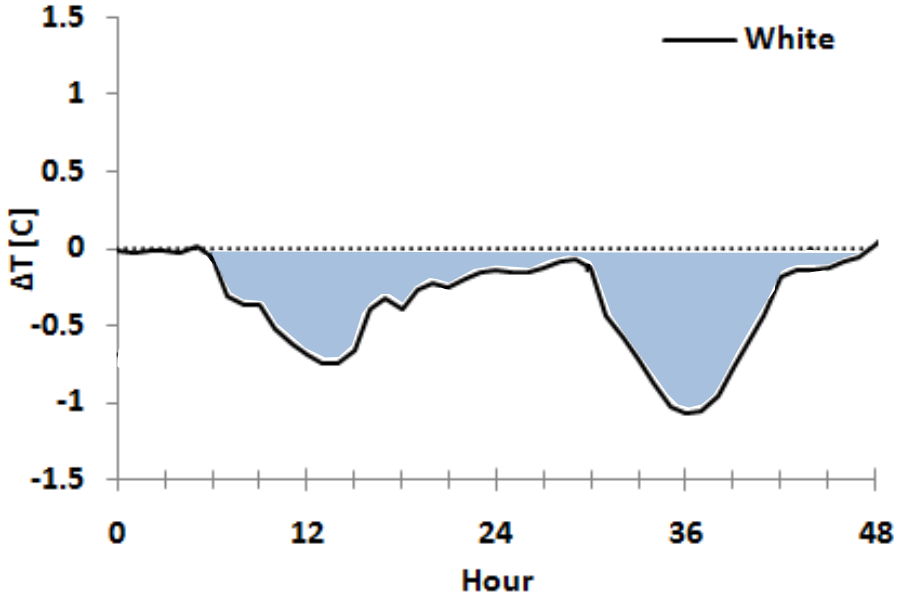


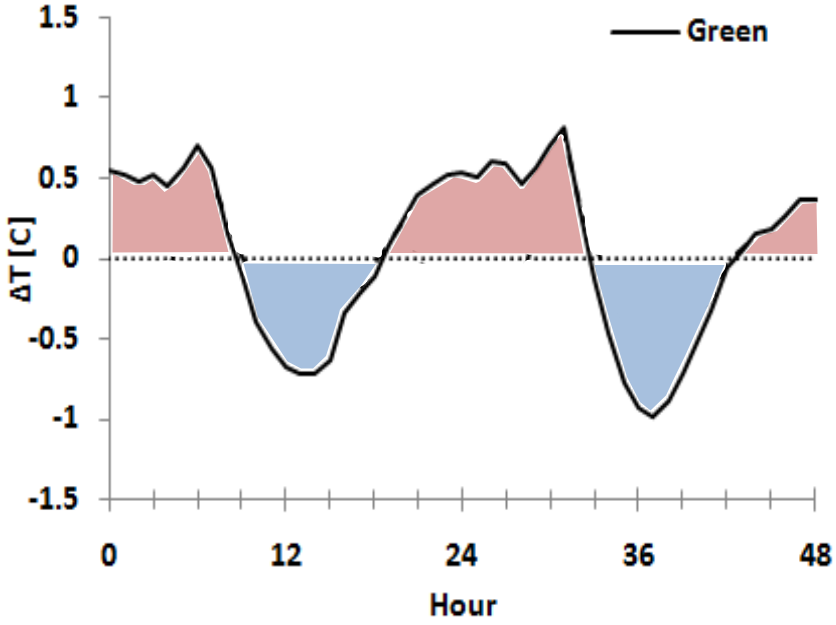
difference…

Run mesoscale model with surface flux perturbation



Effect of 100% white or green roof scenarios on 2-m air temperatures (relative to dark control roofs)

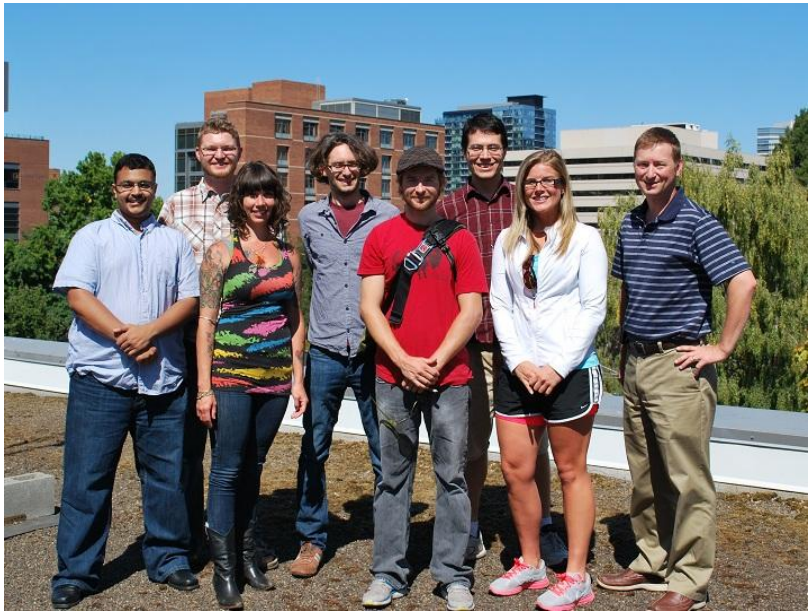




Near-surface (2m) air temperature differences.
Control roof (ρ_{sw} = 0.25 membrane) case as compared with 100% green roofs.
August simulations with mesoscale model (Portland OR)

Green Roof Energy Performance Summary

- Has energy benefits for moderately-insulated roofs, but…
  - savings depend on insulation, schedules, & climate
- Acts as added insulation in winter, but…
  - is less effective when moist
  - can result in undesirable evaporative cooling during shoulder seasons
- Reduces cooling loads in summer, but…
  - may perform better when coupled to building (less insulated)
  - may also improve performance of rooftop AC equipment
- Can help mitigate the summer daytime heat island, but…
  - may adversely affect urban heat island at night
- Has many other important attributes…
  - Storm water, habitat, roof life, noise abatement, etc...



Questions?

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